

Life expectancy and the environment

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2008.48

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July 30, 2008

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Abstract

We present an OLG model in which life expectancy and environmental quality dynamics are jointly determined. Agents may invest in environmental quality, depending on how much they expect to live, but also in order to leave good environmental conditions to future generations. In turn, environmental conditions affects life expectancy. The model produces multiple steady states (development regimes) and initial conditions do matter. In particular, some countries may be trapped in a low life expectancy / low environmental quality trap. This outcome is consistent with stylized facts relating life expectancy and environmental performance measures. Possible strategies to escape from this kind of trap are also discussed. Finally, this result is robust to the introduction of human capital through parental education expenditures.

JEL classification: D62; J13; J24; O11; Q56.

Keywords: Environmental quality; life expectancy; poverty traps.

Résumé

Cet article présente un modèle à générations imbriquées dans lequel les dynamiques de l'espérance de vie et de la qualité environnementale sont conjointement déterminées. Les agents peuvent investir en maintenance environnementale, selon leur espérance de vie, mais aussi afin de laisser un bon environnement aux générations futures. Réciproquement, l'environnement affecte positivement l'espérance de vie. Le modèle offre des équilibres multiples (régimes de développement) et les conditions initiales importent. En particulier, nous montrons comment des économies peuvent être emprisonnées dans trappe environnementale, caractérisée par une faible espérance de vie et une qualité environnementale basse. Par ailleurs, ces conclusions sont cohérentes avec les faits stylisés reliant l'espérance de vie à diverses mesures de performance environnementale. Des stratégies possibles pour sortir de ces trappes sont également discutées. Enfin, ce résultat reste robuste à l'introduction du capital humain à travers des dépenses parentales d'éducation.

Classement JEL: D62; J13; J24; O11; Q56.

Mots-clefs: Qualité environnementale; espérance de vie; trappe à pauvreté.

1 Introduction

Environment is often regarded as an asset that is passed on to future generations but preserving the environment is also important for one's own future utility: whatever the case, environmental care betrays some concern for the future. In addition, life expectancy is one of the main factors affecting the way people value future: a higher longevity makes people more sympathetic to future generations and their future selves. Therefore, if someone expects to live longer he should be willing to invest more in environmental quality.

Consequently, it should not come as a surprise that, as shown in Figure 1, life expectancy is strongly correlated across countries with environmental quality, as proxied by the Environmental Performance Index (henceforth EPI). Notice that such a synthetic indicator (YCELP, 2006) takes into account both "environmental health" (as defined by drinking water, sanitation, pollution, etc.) and "ecosystem vitality", that includes factors like biodiversity, availability of natural resources (forestry, fisheries, etc.), air quality and energy. Therefore, reducing pollution or preserving natural resources may both contribute to improve environmental quality and, clearly enough, countries with a comparable EPI may exhibit very different scores in sub-indicators¹.

Of course, the causal link between life expectancy and environmental quality may also go the other way around. Several studies in medicine and epidemiology, like Elo and Preston (1992) and Evans and Smith (2005), show that environmental quality is a very important factor affecting health and morbidity: air and water pollution, soils deteriorations and the like, are all susceptible of increasing human mortality (thus reducing longevity).

Moreover, a quick look at the data, displaying a bimodal distribution of environmental performance across countries (see Figure 2), suggests the possibility of an *environmental* poverty trap. This concept points to the existence of "convergence clubs" in terms of environmental performance: countries are concentrated around *two* levels of the EPI.

In this paper, we model explicitly the two-way causality between environment and life-expectancy: the dynamic interaction between these two variables can in turn justify the

¹Take for instance United States, Russia and Brazil, that are ranked 28, 32 and 34 respectively, with an EPI ranging from 78.5 to 77. The United States rank very high in environmental health, but very low in the management of natural resources. Russia displays excellent resource indicators, while failing to achieve decent scores in sustainable energy. Finally, Brazil does very well in water quality, but is characterized by extremely low biodiversity indicators. See YCELP (2006) for further examples.

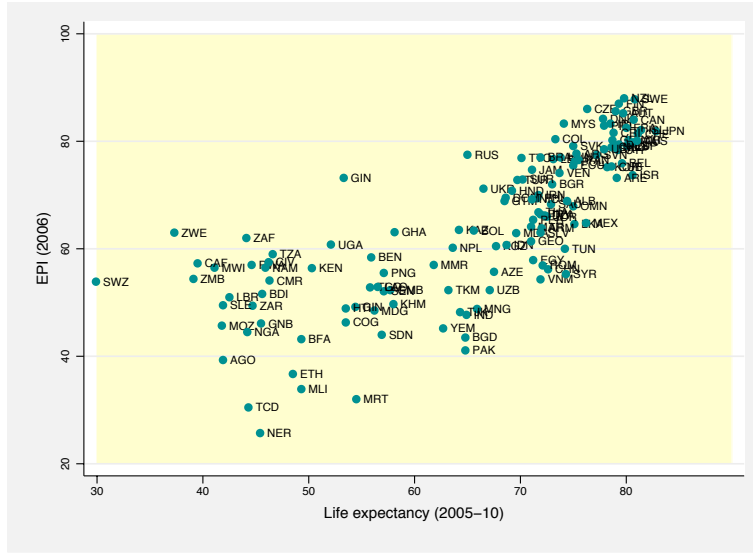


Figure 1: Correlation
Sources: EPI: YCELP (2006), life expectancy: UN (2005)

existence of the environmental poverty trap.

In the benchmark version of our model, we consider overlapping generations of three-period lived agents, who get utility from consumption and environmental quality. During adulthood, when all relevant decisions are taken, they can work and allocate their income between consumption and investment in environmental maintenance: consumption involves deterioration of the future quality of the environment, while maintenance helps improving it. Environmental quality may also be affected by external factors (that are exogenous from our agents' viewpoint). Survival to the last period is probabilistic, and depends on the inherited quality of the environment. In such a setting, environmental care might be motivated by an individual's concern for both self-interest and the interest of future generations.

It is easy to find that optimal choices depend crucially on life expectancy: in particular, a higher probability to be alive in the third period boosts investment in the environment and reduces consumption (the latter translating into less environmental deterioration). Since, as we have already pointed out, life expectancy is endogenous and depends on environmental quality (a healthier environment increases the survival probability), our model allows for

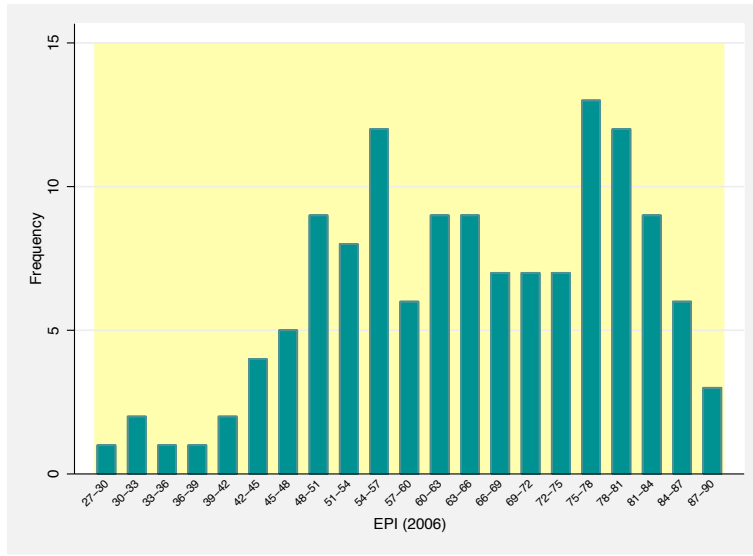


Figure 2: Bimodality
Source: YCELP (2006)

multiple equilibria and may explain the existence of poverty traps. Initial conditions do matter: in particular, a given country may be caught in a high-mortality/poor-environment trap if low income is associated with a deteriorated environment. Possible strategies to escape from the trap will be also identified and discussed.

We also show that the introduction of human capital accumulation would not alter the quality of these results. If parent can use their income also to educate their children, and if survival probabilities are affected by both environmental quality and human capital, we could eventually end up with multiple development regimes. The only difference is that the low-life-expectancy/poor-environment trap would be characterized by low human capital as well.

Our model is primarily related to those papers that have analyzed environmental issues in a dynamic OLG framework. Among them, John and Pecchenino (1994) have been the first to introduce the possibility of multiple equilibria, identifying a case for a poverty trap characterized by poor economic performance and environmental degradation; however, life expectancy is assumed to be exogenous and plays no role in their model, where there is no room for uncertainty. The idea of explaining environmental care with uncertain lifetime

is instead already present in Ono and Maeda (2001), although in their model environmental quality does not affect longevity. On the contrary, Jouvét et al. (2007) consider the impact of environmental quality on mortality, but neglect completely the role of mortality in defining environmental choices and leave no room for maintenance. Furthermore, our model is also somewhat related to Jouvét et al. (2000), in which the degree of inter-generational altruism is used to explain environmental choices.

It could be also interesting to establish a link between our paper and the literature on poverty traps, that has been comprehensively surveyed, for instance, by Azariadis (1996) and Azariadis and Stachurski (2005). With respect to existing papers, we deal with an environmental kind of trap: poverty is not defined in terms of GDP per capita, capital accumulation, etc. but in terms of environmental quality. It is quite clear, however, that we focus only on one specific mechanism lying behind environmental traps; exactly as under-development traps may be related to a wide variety of factors, ranging from financial to technological ones, and including human capital accumulation and life expectancy (Blackburn and Cipriani, 2002), we are perfectly aware that life expectancy is only one of the possible causes of environmental traps.

Our paper is then organized as follows. After this Introduction, Section 2 presents and solves the basic model: there we discuss the existence of an environmental poverty trap and the possible strategies to escape from it. An extended version of the model, allowing for human capital accumulation, is analyzed in Section 3. Section 4 concludes.

2 The basic model

We consider an infinite-horizon economy that is populated by overlapping generations of people living for three periods: childhood, adulthood and old age. Time is discrete and indexed by $t = 0, 1, 2, \dots, \infty$. All decisions are taken in the adult period of life. Individuals live safely through the first two periods, while survival to the third period is subject to uncertainty. We assume no population growth. Furthermore, agents are considered to be identical in each generation, whose size is normalized to one. Preferences are represented by the following utility function²;

$$U(c_t, e_{t+1}) = \ln c_t + \rho \pi_t \gamma \ln e_{t+1}, \quad (1)$$

²We assume a log utility function to get closed-form solutions.

people care about adult consumption (c_t) and environmental quality when old (e_{t+1}); γ (> 0) represents the weight agents give to the future environment (green preferences), ρ (> 0) is the subjective discount factor, while π_t denotes the survival probability (that is taken as given since it depends on inherited environmental quality) and the preference for the future depends on both ρ and π_t . Notice that in our framework an increase (decrease) in the survival probability translates into a higher (lower) life expectancy, so that hereafter we will use the two concepts interchangeably.

Let us underline that e_t may encompass various issues: quality (cleanliness) of water, air and soils, ecosystem vitality (biodiversity, forestry, fisheries), etc.³ Broadly speaking, e_t can be seen as an index of the amenity (use and nonuse) value of the environment. The introduction of e_{t+1} in the individual utility function is consistent with what Popp (2001) defines as "weak altruism": agents decide to provide environmental quality for a combination of both self-interest and the interest of future generations. In other words, people may be willing to engage in environmental maintenance and improvement because they want themselves to enjoy a better environment, or/and because they want to leave a better environment to their offspring⁴.

Adult individuals face the following budget constraint:

$$w_t = c_t + m_t, \quad (2)$$

they allocate their income (w_t) between consumption and environmental maintenance (m_t). In this benchmark version of our model, w_t is assumed to be exogenous⁵. Environmental maintenance summarizes all those actions that agents can take in order to preserve and improve environmental conditions.

Following John and Pecchenino (1994) and Ono (2002), the law of motion of environmental quality is given by the following expression:

$$e_{t+1} = (1 - \eta)e_t + \sigma m_t - \beta c_t - \lambda Q_t, \quad (3)$$

with $\beta, \sigma, \lambda > 0$ and $0 \leq \eta < 1$.

³All these issues are taken into account by the EPI, that we have consistently used as a proxy of environmental quality in Figures 1 and 2.

⁴Purely altruistic motives toward environmental protection can be interpreted as nonuse values, that include option value, the value of simply knowing that a resource exist, and bequest values.

⁵This assumption will be relaxed in Section 3, where we allow for human capital accumulation and consequent income dynamics.

The parameter η is the natural rate of deterioration of the environment, σ represents the effectiveness of maintenance, whereas β accounts for the degradation of the environment due to each unit of consumption. The above formulation also allows for the possibility of external effects (coming from outside economies) on our environment: $\lambda Q_t > 0$ (< 0) represents the total impact of a harmful (beneficial) activity⁶.

Notice that equation (3) implies that agents cannot, through their actions, modify the current state of the environment (e_t). The latter is thus “inherited”, depending only on the choices of the past generation⁷.

Taking as given w_t , e_t and π_t , agents choose c_t and m_t so as to maximize (1) subject to (2), (3), $c_t > 0$, $m_t > 0$ and $e_t > 0$. Optimal choices are then given by:

$$m_t = \frac{\lambda Q_t - (1 - \eta)e_t + [\beta + \rho\gamma(\beta + \sigma)\pi_t]w_t}{(\beta + \sigma)(1 + \rho\gamma\pi_t)}, \quad (4)$$

and

$$c_t = \frac{(1 - \eta)e_t + \sigma w_t - \lambda Q_t}{(\beta + \sigma)(1 + \rho\gamma\pi_t)}. \quad (5)$$

Notice that here, given that agents are identical and the population is normalized to one, aggregate variables (choices) are completely equivalent to individual ones. Moreover, since there is no intra-generational externality, optimal choices at the decentralized level coincide with the social optimum.

From (4) and (5), we can observe that both consumption and environmental maintenance are positively affected by income: richer economies are more likely to invest in environmental care. In addition, current environmental quality has a positive effect on consumption but a negative one on maintenance: environmental investment is less needed if the environment inherited from the past generation is less degraded. These two results have already been established by existing papers like John and Pecchenino (1994) and Ono (2002).

The novelty of our model is that we can identify a specific effect of life expectancy (as determined by the survival probability π_t) on environmental maintenance. As it can be

⁶Oil slicks can be a typical example of $Q_t > 0$, while the preservation of the Amazonian forest could be regarded as a negative Q_t in our model.

⁷Therefore, our results would not change if we introduce current environmental quality (e_t) in the utility function.

easily seen from the following derivative

$$\frac{\partial m_t}{\partial \pi_t} = \frac{\rho\gamma[(1-\eta)e_t + \sigma w_t - \lambda Q_t]}{(\beta + \sigma)(1 + \rho\gamma\pi_t)^2}, \quad (6)$$

that is positive as soon as we have interior solutions, a higher survival probability raises stronger concerns for the future state of the environment, thus inducing more maintenance.

In addition, a relatively larger value of Q_t triggers more investment in maintenance. Notice that the term $\lambda Q_t - (1 - \eta)e_t$ represents the net effect of *external* and *past* environmental conditions on optimal choices.

Once we substitute (4) into (3), we get the following dynamic difference equation:

$$e_{t+1} = \frac{\rho\gamma\pi_t}{1 + \rho\gamma\pi_t} [(1 - \eta)e_t + \sigma w_t - \lambda Q_t]. \quad (7)$$

Until now we have considered π_t as exogenous, although we have pointed out that life expectancy may depend on (bequeathed) environmental quality. Now, we introduce explicitly a function $\pi_t = \pi(e_t)$, such that $\pi'(\cdot) > 0$, $\lim_{e \rightarrow 0} \pi(e) = \underline{\pi}$ and $\lim_{e \rightarrow \infty} \pi(e) = \bar{\pi} \leq 1$. This formulation is consistent with a large body of medical and epidemiological literature showing clear effects of environmental conditions on adult mortality, like for instance Elo and Preston (1992), Pope et al. (1995) and Evans and Smith (2005). The shape of $\pi(e_t)$ may reflect "technological" factors affecting the transformation of environmental quality into survival probability such as, for instance, medicine effectiveness.

The dynamics of our model are now described by:

$$e_{t+1} = \frac{\rho\gamma\pi(e_t)}{1 + \rho\gamma\pi(e_t)} [(1 - \eta)e_t + \sigma w_t - \lambda Q_t] \equiv \phi(e_t). \quad (8)$$

In this framework, a steady-state equilibrium is defined as a fixed point e^* such that $\phi(e^*) = e^*$, which is stable (unstable) if $\phi'(e^*) < 1$ (> 1).

Depending on the shape of the transition function $\phi(e_t)$, we may have different scenarios. For the sake of simplicity, we assume that w_t and Q_t are not only exogenous but also constant, so that $w_t = w$ and $Q_t = Q$. Figure 3 shows that we have only one stable steady-state (e') as long as $\phi(\cdot)$ is concave for all possible values of e_t . Non-ergodicity and multiple steady-states may instead occur if $\phi(\cdot)$ is first convex and then concave, displaying an inflection point⁸. In this case, depending on initial conditions, an economy may end up with either high or low environmental quality (e^H and e^L , respectively).

⁸Notice that this is a direct implication of assuming a convex-concave survival probability $\pi(e_t)$: under

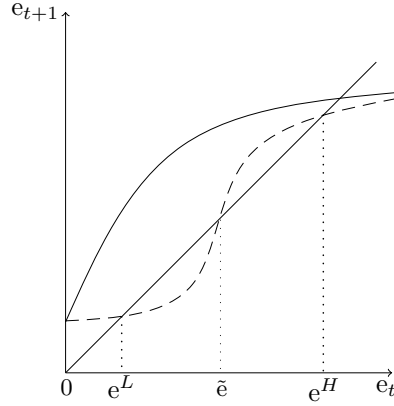


Figure 3: Dynamics

2.1 Poverty trap

The possibility of multiple equilibria implies the existence of an environmental poverty trap. To give an analytical illustration of such a case, we introduce now the following specific functional form relating the survival probability to inherited environmental quality:

$$\pi(e_t) = \begin{cases} \underline{\pi} & \text{if } e_t < \tilde{e} \\ \bar{\pi} & \text{if } e_t \geq \tilde{e} \end{cases}, \quad (9)$$

where \tilde{e} is an exogenous threshold value of the environmental quality, above (below) which the value of the survival probability is high (low). Obviously, we also assume that $\bar{\pi} > \underline{\pi}$. A step function of this kind can be justified considering that only a long term exposure to bad environmental conditions may indeed affect negatively life expectancy (see for instance Evans and Smith (2005) on the effects of air pollution on mortality). The value of \tilde{e} may depend on factors such as medicine effectiveness, health care quality, etc. For instance, a low \tilde{e} can be explained by a very efficient medical technology that makes long life expectancy

low environmental conditions, an improvement of the environmental quality drives a small rise on the survival probability. However, beyond an environmental threshold, this will translate into a much higher life expectancy. A typical example is water, which is considered to serve as drinking water if its chemical characteristics are good enough.

possible even under bad environmental conditions. On the contrary, a high \tilde{e} may represent the case of a developing country where health services are so poorly performing that any deterioration of the environment translates easily into higher mortality.

Given equation (9), the transition function $\phi(e_t)$ becomes:

$$\phi(e_t) = \begin{cases} \frac{\rho\gamma\pi}{1+\rho\gamma\pi}[(1-\eta)e_t + \sigma w - \lambda Q] & \text{if } e_t < \tilde{e} \\ \frac{\rho\gamma\bar{\pi}}{1+\rho\gamma\bar{\pi}}[(1-\eta)e_t + \sigma w - \lambda Q] & \text{if } e_t \geq \tilde{e} \end{cases}. \quad (10)$$

We can then claim the following:

Proposition 1 *If the following condition holds:*

$$\frac{\rho\gamma\pi}{1+\rho\gamma\pi} < \frac{\tilde{e}}{\sigma w - \lambda Q} < \frac{\rho\gamma\bar{\pi}}{1+\rho\gamma\bar{\pi}},$$

then the dynamic equation (10) admits two stable steady-states, given by

$$e^L = [\rho\gamma\pi/(1+\rho\gamma\pi)](\sigma w - \lambda Q) \text{ and } e^H = [\rho\gamma\bar{\pi}/(1+\rho\gamma\bar{\pi})](\sigma w - \lambda Q).$$

Proof. Provided that it exists, any steady-state is stable since, in our model, $\phi'(e_t) < 1, \forall e_t > 0$. Multiplicity arises if $[\rho\gamma\pi/(1+\rho\gamma\pi)](\sigma w - \lambda Q) < \tilde{e} < [\rho\gamma\bar{\pi}/(1+\rho\gamma\bar{\pi})](\sigma w - \lambda Q)$, which yields the condition above. ■

The dynamics of our system are depicted in Figure 4. The threshold value \tilde{e} identifies a poverty trap: an economy starting from an environmental quality between 0 and \tilde{e} will reach the equilibrium point A , which is a steady-state characterized by both low environmental quality (e^L) and short life expectancy (π). However, if initial conditions are such that $e_0 \geq \tilde{e}$, the economy will end up in the "higher" steady-state B , where longer life expectancy ($\bar{\pi}$) is associated with better environmental quality (e^H).

The underlying mechanism goes as follows: for initial environmental quality below the threshold value \tilde{e} , the survival probability is pinned down to π . As it has been previously discussed, shorter life expectancy implies a weaker concern for the future: by optimal choices (4) and (5), and for a given income, a lower survival probability induces agents to substitute environmental maintenance with consumption. Therefore, from equation (10), environmental quality decreases ending up with the lower steady-state value e^L . Symmetrically, if $e_0 \geq \tilde{e}$, our economy is driven to e^H .

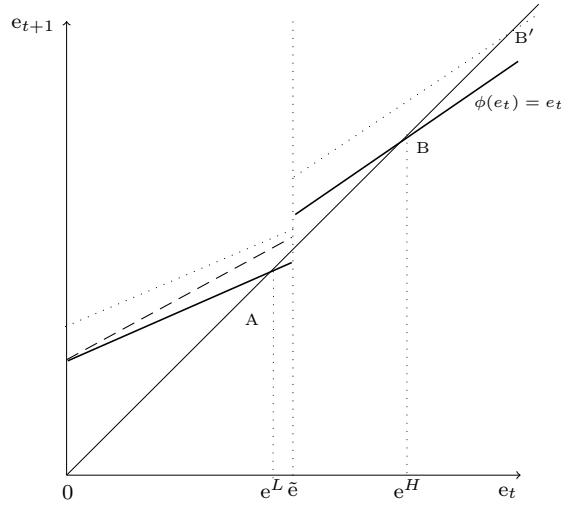


Figure 4: Environmental poverty trap

2.2 Escaping the trap

We conclude this section analyzing different possible strategies to escape from the environmental poverty trap. Let us assume that our economy is initially trapped in the "low" steady-state A , characterized by bad environmental quality and short life expectancy $(e^L, \underline{\pi})$. Technically speaking, we can identify different ways of escaping this trap.

First, as it is clear from Figure 4, a large enough *permanent* reduction in the environmental threshold value \tilde{e} , such that \tilde{e} becomes lower than e^L , will eliminate the low steady-state, thus driving our economy toward the high steady-state B . As we observed in Section 2.1, this may correspond, for instance, to an improvement in medicine effectiveness⁹. The crucial point is that in this new situation, the survival probability associated to e^L is $\bar{\pi}$ instead of $\underline{\pi}$. This implies greater concern about the future, more maintenance (equation (6)), less consumption, and finally convergence to the high (and now unique) steady-state B identi-

⁹De la Croix and Sommacal (2008) have a model in which a rise in medicine effectiveness, through a longer life expectancy, promotes capital accumulation and income growth. In our setting, advances in medicine induce a different kind of investment, i.e. environmental maintenance and improvement.

fied by $(e^H, \bar{\pi})$.

Second, for a fixed \tilde{e} , our economy can still get away from the poverty trap by means of a parallel shift-up of the transition function $\phi(e_t)$ such that the low steady-state A disappears. In this case, there is a unique steady-state that associates $\bar{\pi}$ with an environmental quality level higher than e^H . As it can be inferred from equation (10), such an upwards shift of $\phi(e_t)$ may be induced by (i) a *permanent* income expansion, and/or (ii) a *permanent* reduction of harmful external effects on the environment. In both cases, the environmental quality of our economy increases until it reaches the threshold value \tilde{e} (see Figure 4). Afterward, life expectancy jumps to $\bar{\pi}$ and, due to greater concern about the future, maintenance rises while consumption decreases. Then, the economy converges to the new unique steady-state. A possible real world example of a lowering Q could be the global reduction in pollution due to the implementation of international environmental agreements, such as the Kyoto Protocol.

Third, the inferior steady-state A can be also eliminated by increasing the slope of $\phi(e_t)$ for $e_t \in (0, \tilde{e})$. A steeper transition function may be explained, for instance, by a *permanent* rise in the survival probability in a deteriorated environment (π) that, similarly to the reduction of \tilde{e} mentioned above, can be traced back to technological progress in medical sciences, etc. Here, the underlying dynamics would not be different from the previous cases.

Although until now we have focused on the different opportunities to escape the trap, it should be clear that an economy out of the poverty trap is not safe forever. Intuitively, all the mechanisms we have seen above may work in the opposite direction. For instance, a reduction in w and/or an increase in Q may lead to the elimination of the high steady-state (B in Figure 4) and the economy, that would have otherwise converged to the higher steady-state, can happen to be thrown back in the poverty trap.

Moreover, it is worth noticing that even *temporary* variations of initial conditions may be sufficient to get into the trap. Referring to Figure 4, suppose that the environmental quality of our economy belongs to a small right neighborhood of \tilde{e} : out of external intervention, the economy would converge to the high steady-state B . However, any event susceptible of reducing e_0 below \tilde{e} pushes the economy into "vicious" dynamics, involving a deterioration of both environmental conditions and life expectancy¹⁰. Examples of such events

¹⁰Symmetrically, temporary positive shocks (like a reduction in Q) can help sorting out the trap. It should

may range from natural disasters to episodes of acute pollution like oil slicks. This should raise a concern about the environmental awareness of countries. Neglecting environmental care, bad management of natural resources and too much exposure to environmental risks may make countries vulnerable to even temporary events with heavy long-lasting consequences: in particular, countries with a somewhat fragile environment are prone to pay high costs in terms of human development, through lower life expectancy. Furthermore, we also point out the possibility of countries being trapped in a low life expectancy / low environmental quality trap, if they meet environmental constraints when life expectancy is low. A real-world example of this kind are the African countries which are already very polluted, although having a low life expectancy.

3 Introducing human capital accumulation

In the basic version of our model, income was completely exogenous in every period and we did not allow for any growth mechanism. In this Section, we aim at overcoming these two limitations introducing the possibility of human capital accumulation through education. We want to capture a couple of rather simple ideas: (i) environmental preservation subtracts some resources not only to consumption but also to investment, and (ii) income growth, relaxing the budget constraint, makes more maintenance possible ¹¹.

Agents maximize the following utility function:

$$U = \ln c_t + \pi_t(\alpha \ln h_{t+1} + \gamma \ln e_{t+1}). \quad (11)$$

With respect to (1), we have introduced explicitly inter-generational altruism (of "warm glove" kind): parents care about the human capital level attained by their children (h_{t+1}); the importance attached to this term is measured by α , with $0 < \alpha < 1$. Notice also that here, for the sake of simplicity, we have removed inter-temporal discounting.

An increased survival probability implies that agents value more future environmental quality, exactly as it was in the basic model. Moreover, it makes now agents more sympathetic to their offspring, reinforcing inter-generational altruism.

be noticed that here, escaping from the trap does not imply the elimination of the lower steady-state, while in the three cases discussed above, the trap does not exist anymore.

¹¹Notice that we could tell the same story if we had physical capital instead of human capital, the only difference being that physical capital might be itself involving some pollution.

Production of a homogeneous good takes place according to the following function:

$$Y_t = wh_t, \quad (12)$$

where h_t is also aggregate human capital, once we normalize to 1 the population of our economy.

The budget constraint writes as:

$$wh_t = c_t + m_t + v_t. \quad (13)$$

Agents are paid the exogenous wage rate w for each unit of human capital. Available income may be employed to three alternative purposes: current consumption (c_t), environmental maintenance (m_t) and educational investment (v_t). More precisely, v_t denotes the total amount of education bought by parents for their children, assuming that education is privately funded.

Education is pursued by parents because it can be transformed into future human capital according to the following function:

$$h_{t+1} = \delta h_t^\theta (\mu + v_t)^{1-\theta}, \quad (14)$$

where, depending on θ (with $0 < \theta < 1$), "nature" (parental human capital h_t) complements "nurture" (v_t) in the accumulation of productive skills. Notice that δ (> 0) accounts for total factor productivity in human capital accumulation, while the parameter μ (> 0) prevents human capital from being zero even if parents do not invest in education (as in de la Croix and Doepke, 2003).

Similarly, agents engage in environmental maintenance because it helps improving future environmental quality, according to:

$$e_{t+1} = (1 - \eta)e_t + \sigma m_t - \beta c_t. \quad (15)$$

This formulation reproduces (3), with the exception of the term accounting for external effects, that we have removed for ease of presentation.

Maximizing (11) subject to (13), (14), (15), $c_t > 0$, $m_t > 0$, $e_t > 0$ and $h_t > 0$ leads to the following optimal choices:

$$m_t = \frac{\sigma[\beta + \gamma(\beta + \sigma)\pi_t](\mu + wh_t) - (1 - \eta)[\sigma + \alpha(1 - \theta)(\beta + \sigma)\pi_t]e_t}{\sigma(\beta + \sigma)\{1 + [\alpha(1 - \theta) + \gamma]\pi_t\}}, \quad (16)$$

$$v_t = \frac{\{\alpha(1 - \theta)[(1 - \eta)e_t + \sigma wh_t] - \gamma\mu\sigma\}\pi_t - \mu\sigma}{\sigma\{1 + [\alpha(1 - \theta) + \gamma]\pi_t\}}, \quad (17)$$

and

$$c_t = \frac{(1 - \eta)e_t + \sigma(\mu + wh_t)}{(\beta + \sigma)\{1 + [\alpha(1 - \theta) + \gamma]\pi_t\}}. \quad (18)$$

First of all, it is interesting to compare (16) with (4): the negative association with current environmental quality still holds, as well as the positive effect of income that is now related to *current* human capital. All other things being equal, human capital accumulation makes more resources available for environmental care. Of course, investment in maintenance is negatively affected by α , reflecting the relative substitutability between *future* human capital and *future* environmental quality in the utility function. Finally, the positive effect of life expectancy on environmental maintenance is confirmed, provided that:

$$\gamma\sigma > \alpha(1 - \theta)\beta, \quad (19)$$

in fact:

$$\frac{\partial m_t}{\partial \pi_t} = \frac{[\gamma\sigma - \alpha(1 - \theta)\beta][(1 - \eta)e_t + \sigma(\mu + wh_t)]}{\sigma(\beta + \sigma)\{1 + [\alpha(1 - \theta) + \gamma]\pi_t\}^2}. \quad (20)$$

Condition (19), that we assume to hold henceforth, requires that preferences for environmental quality and the effectiveness of maintenance (γ and σ , respectively) must be strong enough to compensate for the weight attached to education and the detrimental effect of consumption on the environment.

Parental investment in education depends positively on both human capital (because of the traditional income effect and the inter-generational externality implied in (14)) and current environmental quality. If the latter is good enough, requiring a smaller investment in maintenance, it frees resources that can be allocated to education. Moreover, as expected, longer life expectancy induces stronger investment in human capital¹², as shown by the following derivative:

¹²This result, that we obtain for parentally-funded education, is quite common in the literature, although it may be motivated by somewhat different reasons. For instance, Galor (2005, p. 231) claims that "... the rise in the expected length of the productive life may have increased the potential rate of return to investments in children's human capital, and thus could have induced an increase in human capital formation ...". The positive effect of life expectancy on human capital accumulation can be also generalized to self-funded education: since Ben Porath (1967), it has been well established that the expectation of a longer productive life induces agents to invest more in their own human capital.

$$\frac{\partial v_t}{\partial \pi_t} = \frac{\alpha(1-\theta)[(1-\eta)e_t + \sigma(\mu + w_t h_t)]}{\sigma\{1 + [\alpha(1-\theta) + \gamma]\pi_t\}^2}. \quad (21)$$

By replacing (16)-(18) into (14) and (15) we get the following non-linear system of difference equations which describes the dynamics of our economy:

$$h_{t+1} = \delta h_t^\theta \left(\frac{\alpha(1-\theta)[(1-\eta)e_t + \sigma(\mu + w_t h_t)]\pi_t}{\sigma\{1 + [\alpha(1-\theta) + \gamma]\pi_t\}} \right)^{1-\theta} \equiv \xi(e_t, h_t) \quad (22)$$

$$e_{t+1} = \frac{\gamma[(1-\eta)e_t + \sigma(\mu + w_t h_t)]\pi_t}{1 + [\alpha(1-\theta) + \gamma]\pi_t} \equiv \psi(e_t, h_t) \quad (23)$$

In this setup, a steady-state equilibrium is defined as a fixed point (h^*, e^*) such that $\xi(e^*, h^*) = h^*$ and $\psi(e^*, h^*) = e^*$. Similarly to Section 2, we assume the following functional form for the survival probability:

$$\pi_t(e_t, h_t) = \begin{cases} \underline{\pi} & \text{if } e_t + \kappa h_t < J \\ \bar{\pi} & \text{if } e_t + \kappa h_t \geq J \end{cases}, \quad (24)$$

with $\kappa, J > 0$.

This formulation captures the substitutability (accounted for by κ) between human capital and environmental quality in increasing life expectancy. Notice also that J is an exogenous threshold value. In Section 2, we have explained how environmental conditions improve survival probabilities. However, now we also assume that each agent's probability of survival is positively related to his own human capital. Apart from the obvious income effect, this may be justified by the fact that better educated people have access to better information about health, are less likely to take up unhealthy behaviours, smoke, become overweight, etc. It is also consistent with the findings of several empirical studies (see for all Lleras-Muney, 2005).

Equation (24) allows for multiple stable equilibria, as depicted in Figure 5. After defining the two loci $HH \equiv \{(h_t, e_t) : h_{t+1} = h_t\}$ and $EE \equiv \{(h_t, e_t) : e_{t+1} = e_t\}$, we can claim the following:

Proposition 2 *Under proper conditions on the threshold value J , if the slope of HH is larger than the slope of EE , then there exist two stable steady-state equilibria A and B such that $0 < h_A < h_B$ and $0 < e_A < e_B$.*

Proof. See Appendix A ■

Indeed, an economy starting from an environmental quality (e_0) and parental human capital (h_0) low (high) enough ($e_0 + \kappa h_0 < (\geq) J$) will end-up in the steady-state equilibrium A (B), which is characterized by both low (high) environmental quality and parental human capital, and short (longer) life expectancy. Therefore, as in Section 2, the relationship between the survival probability and both the inherited environmental quality and human capital implies the possibility of a country being trapped in an environmental poverty trap. The mechanism behind is similar to the previous set-up. However, by adding human capital, we also introduce the possibility of compensating a low environmental quality by means of higher human capital accumulation. Certainly, an economy initially trapped in the "low" steady-state can escape A by means of higher h_0 (see Figure 5). Nevertheless, an economy out of the poverty trap (B) is not safe forever: the economy falls into the environmental trap if, for instance, there is a massive destruction of human capital.

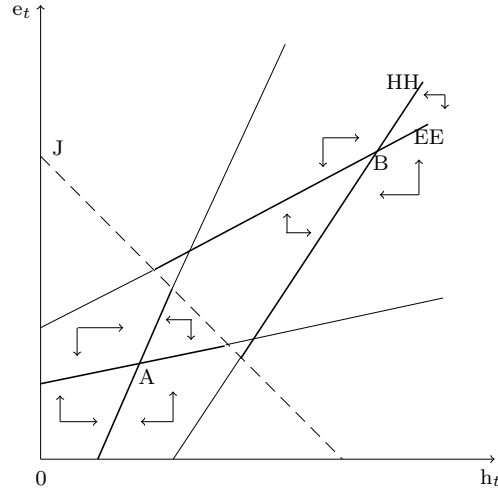


Figure 5: Phase diagram

4 Conclusions

In this paper we have studied the interplay between life expectancy and the environment, as well as its dynamic implications. The basic mechanism, upon which theoretical model is built, is very simple. On the one hand, environmental quality depends on life expectancy, since agents who expect to live longer have a stronger concern for the future and therefore (for altruistic or purely egoistic reasons) invest more in environmental care. On the other hand, it is reasonable to presume that longevity is affected by environmental conditions. By modelling environmental quality as an asset that can be accumulated over time, we have shown that life expectancy and environmental dynamics can be jointly determined, and multiple equilibria may arise. In particular, we have focused on the existence of an environmental kind of poverty trap, characterized by both low life expectancy and poor environmental performance. Possible "escape" strategies, as well as factors affecting the risk to be caught in such a trap, have been discussed. Both the correlation between environmental performance and life expectancy, and possible non-ergodic dynamics, are consistent with stylized facts. Our model is also robust to the introduction of a very simple growth mechanism via human capital accumulation. If education depends on life expectancy, and survival probabilities are affected by both environmental quality and human capital, we can always end up with multiple development regimes, the only difference being that the low-life-expectancy/poor-environment trap would be characterized by low human capital as well.

Finally, as interesting extensions and possible directions for further research, we would suggest: (i) to see how the picture changes if the ongoing growth process itself, and not (only) consumption, puts some pressure on environmental resources; (ii) to introduce heterogeneity among agents, moving from a representative-agent setup to a political economy model, where environmental choices are determined through voting; (iii) to enhance the demographic part of the model, allowing for endogenous fertility and relating environmental quality to demographic factors other than longevity (population density, for instance).

Appendices

A Proof of proposition 2

The proof is organized as follows. First, the two loci HH and EE are characterized. Finally, we study the existence, multiplicity and stability of the steady-state equilibria.

Let us recall the definition of the two loci $HH \equiv \{(h_t, e_t) : h_{t+1} = h_t\}$ and $EE \equiv \{(h_t, e_t) : e_{t+1} = e_t\}$.

A.1 Locus HH

From equation (22) we get that $h_{t+1} - h_t = \xi(e_t, h_t) - h_t$, where π_t is given by equation (24). Therefore, the locus HH writes as:

$$e_t = -\frac{\sigma\mu}{1-\eta} + \frac{\sigma\{1 + [\alpha(1-\theta) + \gamma]\pi_t\} - \sigma\alpha(1-\theta)w\pi_t\delta^{\frac{1}{1-\theta}}}{\alpha(1-\theta)(1-\eta)\pi_t\delta^{\frac{1}{1-\theta}}}h_t, \quad (\text{A.1})$$

where $\pi_t = \underline{\pi}(\bar{\pi})$ for $e_t + \kappa h_t < (\geq)J$. As we can see in Figure 5, locus HH is a discontinuous function divided into two parts (both straight lines) by $e_t = J - \kappa h_t$. The intersection with the y -axis (i.e. the intercept $e_{t_{HH}}|_{h_t=0}$) equals $-\frac{\sigma\mu}{1-\eta} < 0$, and the slope is given by

$$\frac{\partial e_t}{\partial h_t} = \frac{\sigma\{1 + [\alpha(1-\theta) + \gamma]\pi_t\} - \sigma\alpha(1-\theta)w\pi_t\delta^{\frac{1}{1-\theta}}}{\alpha(1-\theta)(1-\eta)\pi_t\delta^{\frac{1}{1-\theta}}} \equiv s_h(\pi_t), \quad (\text{A.2})$$

where $\pi_t = \underline{\pi}(\bar{\pi})$ for $e_t + \kappa h_t < (\geq)J$. Indeed, as it is clear from equation (A.2), $s_h > 0$ is equivalent to having a positive numerator. Moreover, one can also verify that $\partial s_h(\pi)/\partial \pi < 0$. This implies that the slope of the first portion of the locus HH (given by $s_h(\underline{\pi})$) is larger than the slope of the second part ($s_h(\bar{\pi})$) (see Figure 5).

A.2 Locus EE

Equation (23) yields $e_{t+1} - e_t = \psi(e_t, h_t) - e_t$, where π_t is given by equation (24). Therefore, the locus EE can be expressed as:

$$e_t = -\frac{\gamma\sigma\mu\pi_t}{\gamma(1-\eta)\pi_t - \{1 + [\alpha(1-\theta) + \gamma]\pi_t\}} - \frac{\gamma\sigma w\pi_t}{\gamma(1-\eta)\pi_t - \{1 + [\alpha(1-\theta) + \gamma]\pi_t\}}h_t, \quad (\text{A.3})$$

where $\pi_t = \underline{\pi}(\bar{\pi})$ for $e_t + \kappa h_t < (\geq)J$. As for HH , the locus EE is a discontinuous function divided into two parts (ones more straight lines) by $e_t = J - \kappa h_t$. The intercept $e_{t_{ee}}|_{h_t=0}$ is given by:

$$-\frac{\gamma\sigma\mu\pi_t}{\gamma(1-\eta)\pi_t - \{1 + [\alpha(1-\theta) + \gamma]\pi_t\}}, \quad (\text{A.4})$$

while the slope of EE is:

$$\frac{\partial e_t}{\partial h_t} = -\frac{\gamma\sigma w\pi_t}{\gamma(1-\eta)\pi_t - \{1 + [\alpha(1-\theta) + \gamma]\pi_t\}} \equiv s_e(\pi_t), \quad (\text{A.5})$$

where $\pi_t = \underline{\pi}(\bar{\pi})$ for $e_t + \kappa h_t < (\geq) J$. Indeed, one can easily observe that the denominator of the previous equation is strictly negative. Therefore, $s_e > 0$ and $e_{t_{ee}}|_{h_t=0} > 0$. Moreover, since $\partial(e_{t_{ee}}|_{h_t=0})/\partial\pi > 0$, the y -intercept corresponding to $\pi_t = \bar{\pi}$ is greater than the one defined by $\pi_t = \underline{\pi}$. Finally, we also observe that $\partial s_e(\pi)/\partial\pi > 0$. Consequently, the slope of the first portion of the locus EE (given by $s_e(\underline{\pi})$) is smaller than the slope of the second part ($s_e(\bar{\pi})$) (see Figure 5).

A.3 Existence, multiplicity and stability of steady-states

Provided that $s_h > s_e$, there exist two points $A \equiv (h_A, e_A) = EE(\underline{\pi}) \cap HH(\underline{\pi})$ and $B \equiv (h_B, e_B) = EE(\bar{\pi}) \cap HH(\bar{\pi})$, such that $0 < h_A < h_B$ and $0 < e_A < e_B$. A and B are *both* steady-states if $e_A + \kappa h_A < J < e_B + \kappa h_B$ ¹³. The meaning of this condition can be simply understood looking at Figure 5: it implies that the dashed line $e_t + \kappa h_t = J$ lies between A and B .

Let us now study the *stability* of the A and B . Consider first the locus HH , and take a point $(\bar{h}, \bar{e}) \in HH$. For a fixed $e_t = \bar{e}$ and using (A.1), the dynamics of h_t are given by the following expression:

$$\Delta h_t = \delta h_t^\theta \left\{ \frac{1 + [\alpha(1-\theta) + \gamma]\pi_t - \alpha(1-\theta)w\pi_t\delta^{\frac{1}{1-\theta}}}{1 + [\alpha(1-\theta) + \gamma]\pi_t} \bar{h} + \frac{\alpha(1-\theta)w\pi_t}{1 + [\alpha(1-\theta) + \gamma]\pi_t} \right\}^{1-\theta} - h_t, \quad (\text{A.6})$$

where $\pi_t = \underline{\pi}(\bar{\pi})$ for $e_t + \kappa h_t < (\geq) J$. If $s_h > s_e$, then the numerator of equation (A.2) is positive because $s_e > 0$. Consequently, we can verify that for $h_t > (<) \bar{h}$, $\Delta h_t < (>) 0$. Hence, h_t decreases (increases) (see Figure 5). Similarly, let us consider a point $(\bar{h}, \bar{e}) \in EE$. For a fixed $h_t = \bar{h}$ and taking (A.3), the dynamics of e_t are given by the following expression:

$$\Delta e_t = \frac{\gamma(1-\eta)\pi_t - \{1 + [\alpha(1-\theta) + \gamma]\pi_t\}}{1 + [\alpha(1-\theta) + \gamma]\pi_t} (e_t - \bar{e}), \quad (\text{A.7})$$

where $\pi_t = \underline{\pi}(\bar{\pi})$ for $e_t + \kappa h_t < (\geq) J$. Indeed, since the numerator is negative, it is clear that for $e_t > (<) \bar{e}$, $\Delta e_t < (>) 0$. Hence, e_t decreases (increases) (see Figure 5).

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¹³Notice that we can easily get closed-forms of the steady-state equilibria A and B (available upon request) by combining the equations (A.1) and (A.3).

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